Ultrasonic Measurement of Tension in Steel Components of Civil Structures

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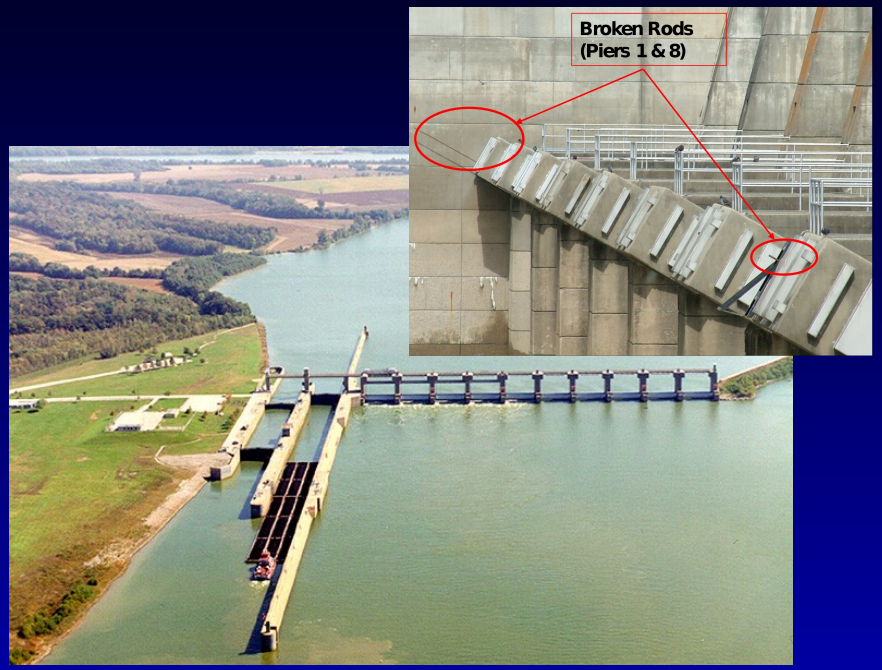
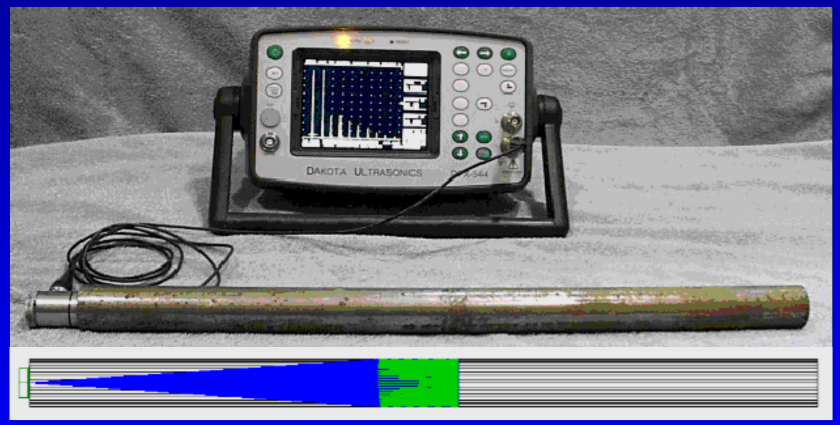
Capability and Product

- **Capability**
  - **NonDestructive test technique for quantitatively measuring tension and corrosion of steel members**
- **Product**
  - **Acoustic-based portable instrument for testing tension and corrosion of both embedded and exposed steel members**



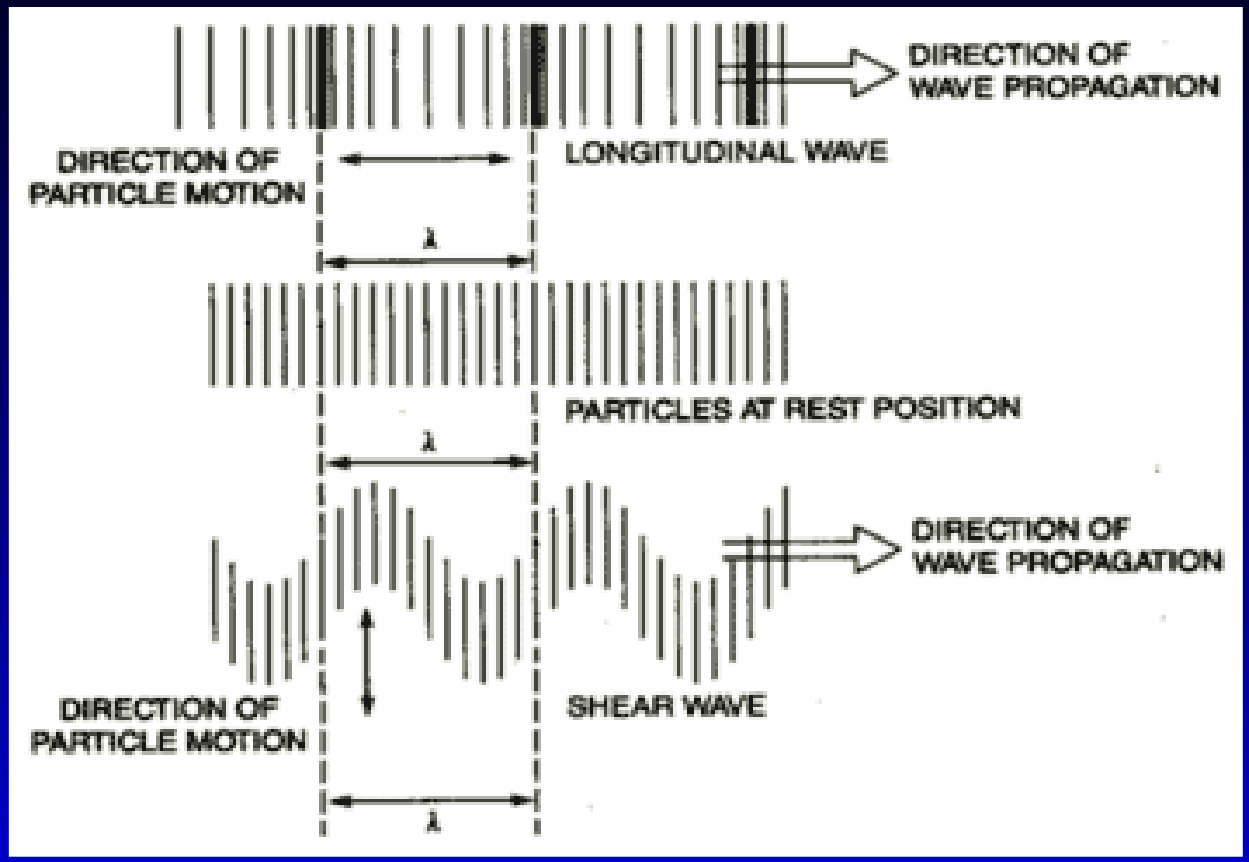


Applications and Benefits

- **Applications**
  - Dam tainter gate anchor rods
  - Lock gate diagonal bracing
  - Post-tensioned steel members in bridges and parking garages

- **Benefits**
  - Rapidly measures tension and corrosion in the field
  - Works with only limited access to part
  - Provides evaluation of fitness for service
  - Improves infrastructure reliability
  - Decreases maintenance costs

Longitudinal and Shear Waves



In non-porous solid materials, such as metals, there are two propagating ultrasonic waves, longitudinal and shear.

Theory of Ultrasonic Tension Measurement

Hooke's Law

$$\sigma_{ij} = \lambda\, \delta_{ij}\, \varepsilon_{aa} + 2\, \mu\, \varepsilon_{ij}$$

Young's Modulus

$$E = \mu\,(3\,\lambda + 2\,\mu) / (\lambda + \mu) = \sigma$$

Bulk Modulus

$$K = \lambda + 2\,\mu / 3 = \sigma_{xx} / (3\,\varepsilon_{xx}) = \sigma_{yy} / (3\,\varepsilon_{yy}) = \sigma_{zz} / (3\,\varepsilon_{zz})$$

Shear Modulus

$$\sigma_{zx} = 2\,\mu\,\varepsilon_{zx}$$

Poisson's Ratio

$$\nu = \lambda / 2\,(\lambda + \mu)$$

Longitudinal Wave Speed

$$V_l = (c_{11} / \rho)^{1/2}$$

Shear Wave Speed

$$V_s = (c_{44} / \rho)^{1/2}$$

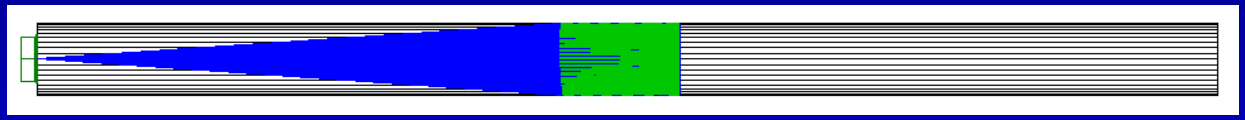
We combined and rearranged the 7 equations above to obtain an equation that relates tension to two ultrasonic speeds.

$$\sigma = (V_l^2 - 2\,V_s^2) / 2(V_l^2 - V_s^2)$$

Using Ultrasound to Obtain Tension Measurements

- The key to measuring tension in a component is to obtain both longitudinal and shear wave speeds with a high degree of accuracy. There are two ways to do this:
  - The simulator can be used to obtain the shear wave speed from measurements of two echoes, as well as the longitudinal wave speed, thus enabling the calculation of tension in components.
  - A special sensor (which we described in a patent disclosure) can be used to measure longitudinal and shear wave speeds directly (and potentially, more accurately).

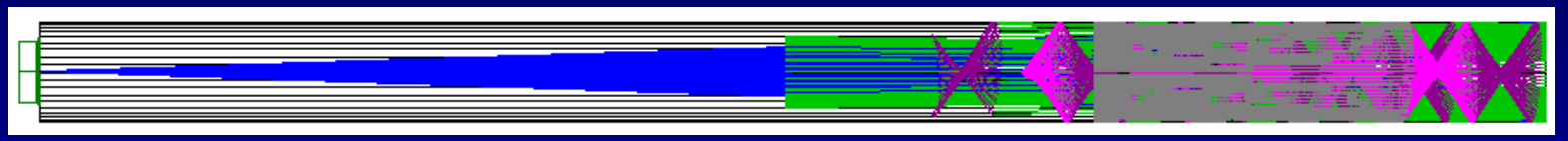
Experiment Simulating Echoes Inside a Steel Rod



A steel rod is on the top (with the echoes showing on the instrument's screen), and the wavefront simulation leading to those echoes is on the bottom.

Simulated Tension Measurement

$t_{e2} = x_2 / V_l + x_3 / V_l + x_4 / V_s + x_5 / V_l$ (e2 shown on slide 17)

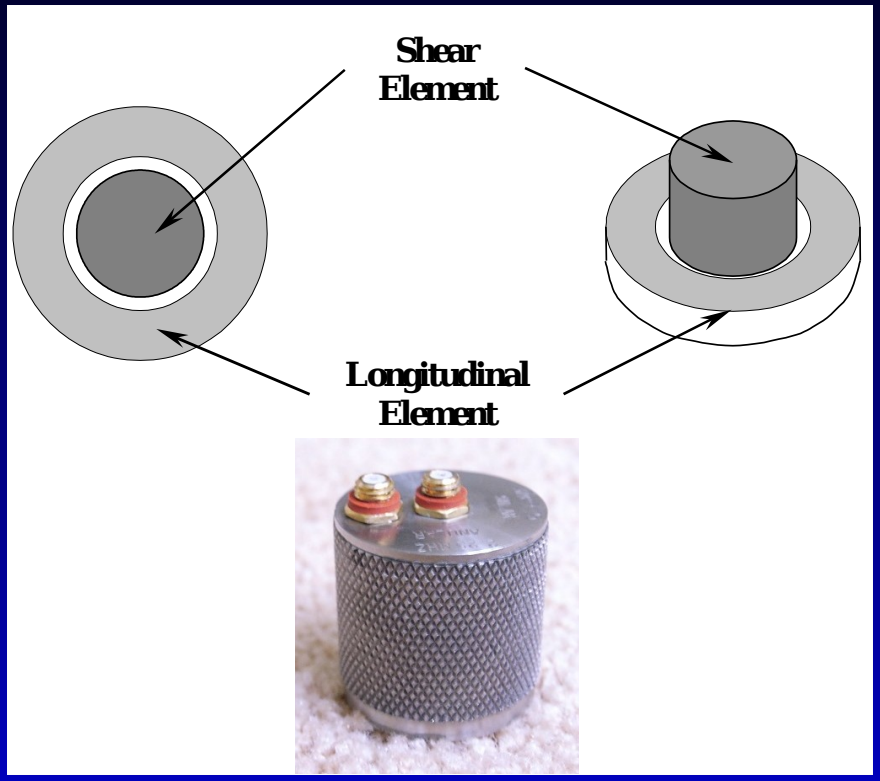


$t_{e3} = x_2 / V_l + x_3 / V_l + x_4 / V_s + x_6 / V_s + x_7 / V_l$ (e3 shown on slide 17)

$$V_s = (x_6 V_l) / (V_l (t_{e3} - t_{e2}) + x_5 + x_7)$$

The simulator can be used to obtain the tension measurement when using only a longitudinal sensor. Two echo times and longitudinal speed are measured; the simulator provides the three path lengths.

Measuring Tension Using a Unique Dual Mode Sensor



Our unique sensor can generate both longitudinal and shear waves from within the same housing, permitting the wave speeds of both modes to be measured with a high degree of accuracy.

Field Verification of Technique

Field testing is planned to take place at Keystone Dam, Tulsa, Oklahoma and R.F. Henry Dam, Selma, Alabama this summer.

Conclusions and Future Work

- **Conclusions**
  - Developed a means of measuring tension ultrasonically
  - Developed an ultrasonic simulator to predict wave propagation and help make tension field measurements easier
  - Developed a unique sensor to make the tension measurement more accurate in the field
  - Submitted a patent disclosure on the new method
  - Developed a prototype instrument
  - Laboratory evaluation of instrument and verification of the theory is presently being conducted
- **Future Work Plans**
  - Develop analytic correlation for degree of corrosion
  - Field evaluation of instrument planned for later this summer